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Numerical Investigation on Thermal Hydraulic and Transit time Characteristics of Density Wave Oscillations

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Abstract

The study of two-phase flow instability attracts lots of attention due to its significance and complexity. Density wave oscillations are the most common dynamic instability, one type of flow instability, in two-phase systems. In this paper, various channel models are constructed based on RELAP5. The 3×3 channel is chosen to analyze the stability and operation security of the system based on the comparison of stability boundaries. For the understanding of basic phenomenon, thermal hydraulic and transit time characteristics in the 3×3 channel are analyzed. The period of flow rate oscillations is an almost constant value along the axial direction. There is a phase lag between inlet and outlet which is nearly equal to 1/2 oscillating period. Flow oscillations may cause dryout when oscillations are divergent. This phenomenon is dangerous for reactors, and should be avoided. For the analysis of the decrease of CHF induced by oscillatory flow, the transit time is taken into consideration as an crucial parameter. The correlation developed by Masini et al. is the most accurate for transit time evaluation by comparison of different methods. Based on the analysis of parameters effect, transit time is positive with subcooled number N_{sub}. Transit time decreases linearly, and then transit time becomes flat with the increase of pressure when N_{sub} is fixed.

Keywords: Density wave oscillations; RELAP5 ; 3×3 channel; Transit time; Thermal hydraulic characteristics

1. Introduction

Two-phase flow instabilities are very common in two phase systems, such as boiling water reactor (BWR), steam generation, condenser, heat exchanger and so on. Normally, flow instability decrease the performance of operation conditions and are harmful to the performance of apparatus and systems. Two-phase flow instability may result many unwanted events, such as mechanical vibrations, thermal fatigue damage, problems of system control and boiling crisis, which occurs in some critical situations and may result in a severe accident.

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The study of two-phase flow instability can be divided into three steps. In the first step, classical flow instabilities were researched maturely, such as Ledinegg instability, density wave oscillation and pressure drop oscillation. Many models and methods were developed to predict the stable region. In the second step, with the discovery of new instabilities in the 1970s, many new problems came together, the most important being non-linear characteristic. Those instabilities mainly come from transit and accident conditions when the emergency core cooling system starts to work. In the last step, the studies for instabilities focused on transit characteristic in a passive cooling system of new generation reactors, for instance, advanced boiling water reactor (ABWR), advanced pressurized water reactor (APWR) and low temperature heating reactor.

Generally, flow instability is classified into static instabilities and dynamic instabilities, according to the characteristics of flow [1]. Due to different mechanisms there are many different types under these two. In this paper, the author pays attention to density wave oscillation, caused by feedback and delay effects between density, pressure drop and flow rate, which belongs to dynamic instabilities. Single channel, parallel channel and channel with a bypass are thoroughly studied by researchers in the past. However, few researchers pay enough attention to flow instabilities, which may occur in the reactor core in transit operation or accident conditions.

Ambrosini et al. utilized system code RELAP5 to study flow instability in the boiling channel. Different combinations of flow model, numerical scheme and nodes number were analyzed. The conclusion made by the authors was that the non-homogeneous, non-equilibrium model combined with semi-implicit numerical scheme was the most suitable combination for analysis of flow instability in boiling channel. Authors suggested that appropriate nodes should be selected for calculation convergence. Some physic characteristics of density wave oscillation were confirmed simultaneously [2].

Colombo et al. carried on the research about density wave instabilities in both a single channel and two parallel channels. Effects of channel length, channel inclination and bypass diameter for density wave oscillations were analyzed in this paper. The conclusion was that the heated wall had to be thin, and with low heat capacity and high heat conductivity in order to avoid the distortion of heat flux [3].

Dae-Hyun Hwang et al. explored the characteristics of two-phase flow instability under APWR conditions. The authors observed the parametric effects of the axial power shape, unheated riser, and channel inlet throttling on the onset of flow instability (OFI). The authors observed that a long unheated riser at the exit of the channel destabilized the system. A center-peaked axial power shape (APS) stabilized the channel at low inlet subcooling conditions, whereas it destabilized the system at higher inlet subcooling conditions. According to the investigation, critical heat flux (CHF) prior to OFI was observed at 16 MPa, and a CHF occurrence simultaneously with a flow oscillation was observed at low inlet subcooling under 11 MPa [4].

In this paper, authors compare the stability boundaries of three different channels based on numerical calculation. The 3×3 channel is suitable for the analysis of flow instability in subchannels in accordance with the comparison result. When density wave oscillations occur, thermal-hydraulic and transit time characteristics in a 3×3 channel are analyzed.

Nomenclature

BWR	boiling water reactor
ABWR	advanced boiling water reactor
APWR	advanced pressurized water reactor
OFI	onset of flow instability
APS	axial power shape
CHF	critical heat flux
LWR	light water reactor
N_{pch}	phase change number
N_{sub}	subcooled number